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EVALUATION OF POTHOLE BLASTING FOR WATERFOWL IN COLORADO

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FOREWORD

Over the years, many factors have caused waterfowl habitat to become more and more of a premium. This is especially true of breeding or production habitat in the United States and lower Canadian Provinces. Drought cycles, of course, can temporarily severely limit production and brood-rearing simply through lack of or drying up of normally suitable areas. However, drainage of marshes and other wetland types for agricultural purposes or even for housing and industrial sites is on the increase and effects permanent losses of habitat of ducks, geese, and many other species.

In recent years, increasing attention has been given to saving and improving remaining wetlands in order to keep them as productive as possible. Emphasis also has been placed on trying to devise methods for improvement of poorer wetlands, i.e., those so choked with vegetation that little or no use is obtained by waterfowl during any period of the year.

A number of studies have been conducted in several states in the last decade or so regarding the feasibility and economics of blasting potholes in wetland areas to improve or produce more duck habitat. For the most part, these individual studies have been somewhat limited in scope, answering a specific question such as duck use by season, efficiency in size of holes produced (as measured by duck use), and longevity and usefulness of the various sizes of potholes produced. Objectives of the investigation covered in this report were designed to include all of these items. This report details the economic feasibility of gain in duck use, by season, per amount of expenditure, and documents the life expectancy of the various sizes of potholes produced under the specific conditions and soil types present in the study area.

It is felt that the resulting information will be extremely useful to managers anticipating, actively planning, or already involved in waterfowl habitat improvement programs, whether on a local or more widespread basis.

Howard D. Funk

Howard D. Funk
Wildlife Research Leader

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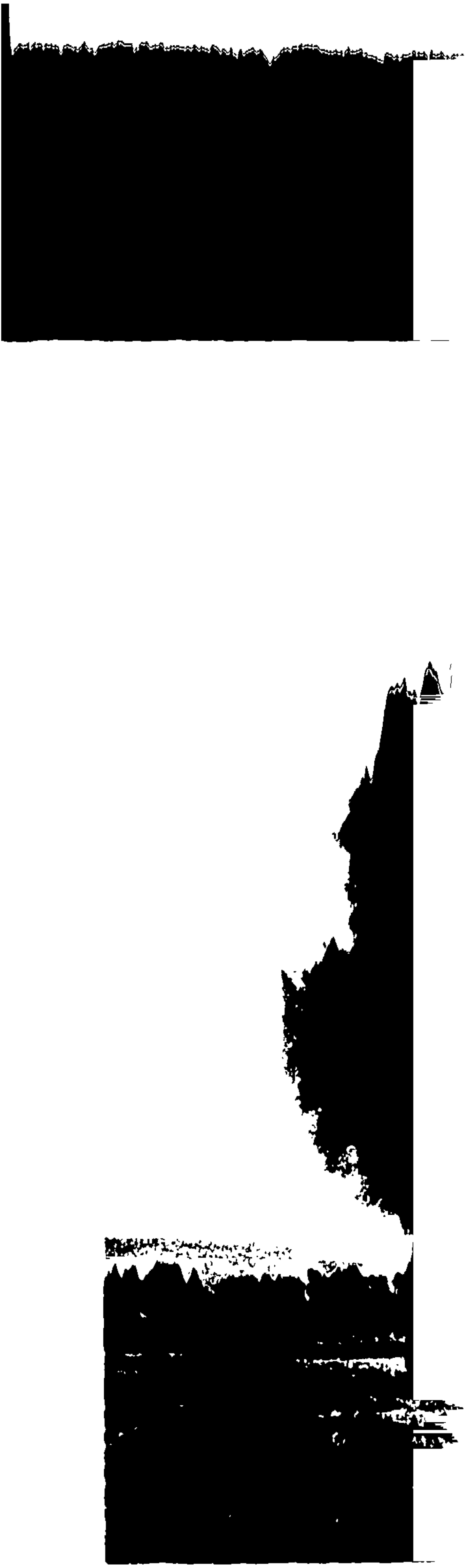

Frontispiece—Detonation of a charge of ammonium

[illegible] oil mixture on the Bonny Reservoir study area. (Photo by Dan Clamp)

EVALUATION OF POTHOLE BLASTING FOR WATERFOWL IN COLORADO

ABSTRACT

Comparisons were made among potholes blasted with four different charge sizes of ammonium nitrate-fuel oil mixtures in terms of cost, waterfowl use, and life expectancy during 1968-1975. The total number of potholes studied was 82 during 1968-1970, 78 in 1973, and 69 in 1975. Despite similar mean depths of potholes among charge sizes, a mean depth loss of 10 in. (26%) occurred during the 7-yr period. This amount of loss was consistent among charge sizes. Over 1,700 duck-visits were recorded during the study, with the greatest amount of use occurring in the spring. There was a highly significant difference in duck use of potholes among the four charge sizes: (1) 75- and 150-lb potholes received more use than did either the 25- or 50-lb potholes; (2) 150-lb potholes attracted more use than 75-lb potholes; and (3) no difference was indicated between 25- and 50-lb potholes.

The efficiency of the charge sizes in terms of duck use, both from cost and surface-area standpoints, increased with increase in charge size. Invasion of the potholes by emergent vegetation was effective in reducing the size of the open-water areas, and this was the major factor believed to determine the quantity of duck use received by the potholes and, ultimately, their "management" longevity. The size of the open-water areas, as determined by charge size, was directly related to the amount of duck use received before and after emergent encroachment. The 75- and 150-lb potholes maintained the largest open-water areas throughout the study, thereby exceeding potholes of the other two charge sizes in "management" longevity.

INTRODUCTION

Because of past and continuing losses of wetlands, waterfowl managers are faced with doing a better job of managing the remaining habitat and with creating new habitats that are both effective and efficient. Waterfowl habitat development, possible through a variety of techniques, has been given considerable attention by state, federal and private conservation organizations for many years. Perhaps of less concern in this endeavor has been the evaluation of such development techniques, especially in terms of the maintenance of wetlands in the most attractive state for optimum waterfowl use. Before applying maintenance procedures, the manager must have some knowledge regarding when the developed area has lost its appeal to waterfowl and what factors contributed to this loss.

Pothole blasting has been one means of improving wetlands for waterfowl by creating open-water areas in marsh vegetation (Frontispiece). This was first accomplished by use of dynamite (Scott and Dever 1940, Provost 1948), but the use of ammonium nitrate-fuel oil mixtures (AN-FO) as the blasting agent has become popular in more recent years (Mathisen *et al.* 1964, Mathiak 1965; Hopper 1973). Provost (1948), and Strohmeyer and Fredrickson (1967) in a follow-up study, evaluated dynamited potholes in Iowa from the standpoint of [illegible] vegetation changes over time, but did little to [illegible] effects of these changes to actual use of the [illegible] waterfowl. Hoffman (1970), on the other hand, [illegible] on a study of potholes blasted with AN-FO [illegible] Manitoba, systematically recorded [illegible] ly-created potholes without reference [illegible] vegetation changes of the potholes.

A study was initiated [illegible] in 1967 to compare potholes blasted [illegible] ent charge sizes of AN-FO in terms [illegible] use, and life expectancy. The study [illegible] period of 8 yrs (1967-1975), but [illegible] tion was conducted during five field seasons [illegible] 1970, 1973, and 1975. Hopper (1973) reported [illegible] first 3 yrs of the study, which dealt primarily with waterfowl use in relation to size and cost of the [illegible] present paper addresses the entire 8-yr span of the study, but gives special emphasis to the life-expectancy phase of the investigation.

STUDY AREA

The study was conducted on a 70-a bottomland marsh at the west end of the Bonny Reservoir State Wildlife Area in Yuma County, east-central Colorado, about 25 mi (40.2 km) north of Burlington (Figs 1 and 2). Bonny Reservoir, a Bureau of Reclamation impoundment, was designed to control the floodwaters of the South Fork of the Republican River and Landsman Creek. It is a major waterfowl migration and wintering area, but attracts only moderate numbers of breeding birds.

The study area is classed as a "Type 3" wetland (shallow fresh marsh) according to the classification system of Martin *et al.* (1953). It lies on the river floodplain and is characterized by water-logged surface soils because of the high water table created by the adjacent river and reservoir. Subsurface soils are predominantly sandy, while surface soils vary from heavier clays near the south (bench) area, to mostly sand along the river.

Common plant species associated with the study area include common three-square (*Scirpus americanus*), sedges (*Carex* spp.), common spikerush (*Eleocharis palustris*), Baltic rush (*Juncus balticus*), broadleaf cattail (*Typha latifolia*), squirreltail (*Sitanion hystrix*), and white sweetclover (*Melilotus alba*). Stands of broadleaf cattail are most extensive in the eastern portion of the study area, while white sweetclover is mainly in the western portion. The vegetation is very dense on the area as a whole, and the absence of livestock grazing yields heavy residual cover from year to year (Fig 3).

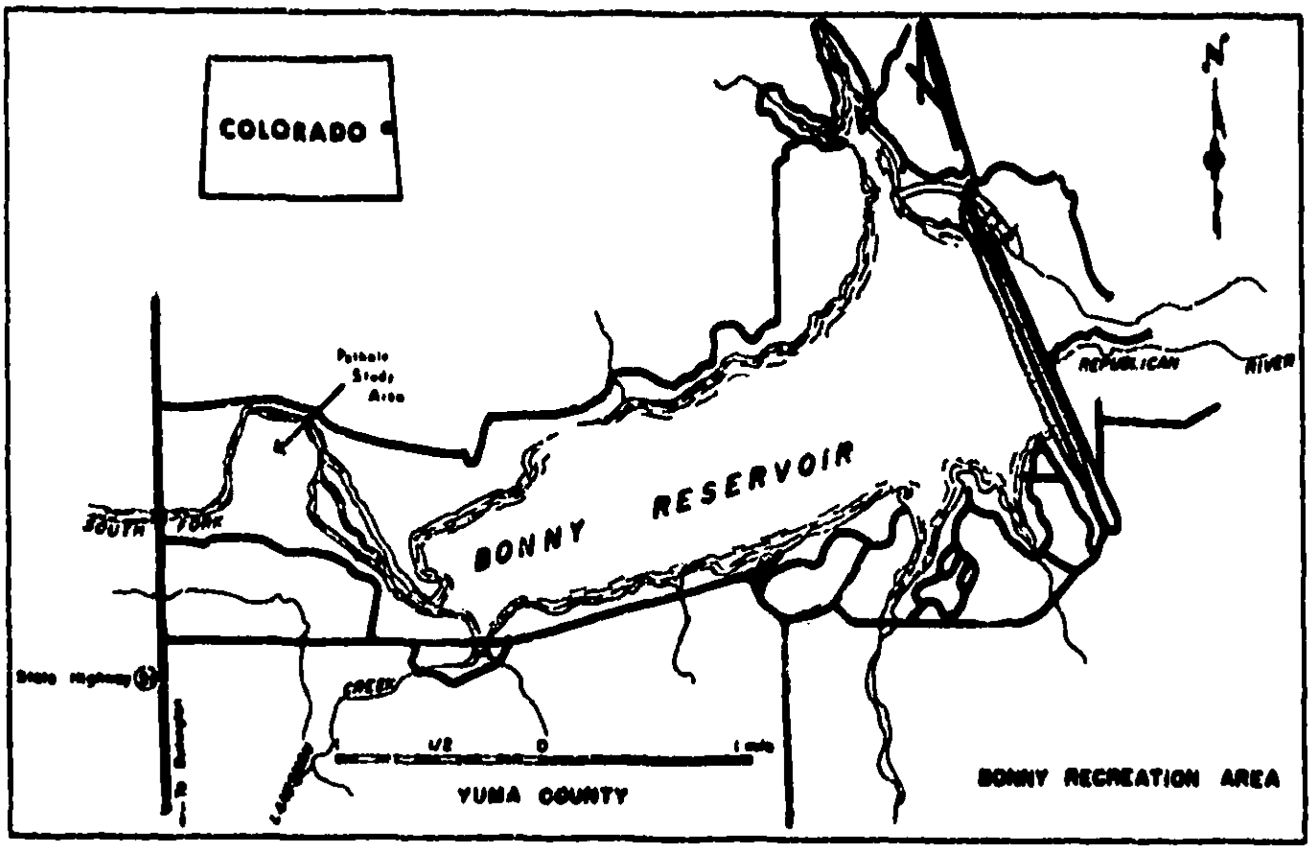

Figure 1—Bonny Reservoir State Wildlife Area, showing location of pothole study area at the west end of the property.

Figure 2—General view of the pothole study area, consisting of a bottomland marsh bordered on the north by the South Fork of the Republican River. (Photo by R. M. Hopper)

Figure 3—Dense stands of common threesquare and broadleaf cattail dominated much of the study area at the beginning of the study. (Photo by R. M. Hopper)

METHODS

Pothole Blasting

Three replications, with four different sizes of charges of AN-FO, were used to evaluate blasted potholes (Fig. 4). Three blocks, each 450 × 900 ft, were laid out on the 70-a marsh and designated A, B, and C. Similar gradations of soil were made available in all blocks by situating the blocks side by side and perpendicular to the north-south change in soil texture. A buffer zone, 300 ft wide, was established between the blocks to set them apart.

A Brunton-type surveying compass and a 150-ft tape were used to locate 28 points in each block, each point representing a pothole blasting site. These points, placed in 4 rows of 7 each, were 150 ft apart, both within and between rows. The points were marked with stakes.

The four charge sizes tested were single charges of 25 and 50 lbs each and multiple charges of 75 and 150 lbs each. Three 25-lb charges placed 11 ft apart in the form of a triangle constituted the 75-lb multiple charge. Similarly, three 50-lb charges set 15 ft apart resulted in the 150-lb multiple charge. One charge size was randomly assigned to each row of Block A. Each of the other sizes was then replicated in Blocks B and C, with the following restrictions: a given size could not occupy (1) an outside row in more than two blocks, (2) the same row (position) in any two blocks; or (3) adjacent rows between blocks (Fig. 4).

All charge holes were dug 30 in. deep with manual posthole diggers. Holes for 25- and 50-lb charges (both single and multiple) were made 10 and 15 in. in diameter, respectively. Charges measured 15 in. high when placed in plastic bags; therefore, the tops of all charges were consistently 15 in. below ground surface when set into position.

Eighty-four potholes were blasted in the three blocks during mid-August 1967, using the procedures and safety precautions recommended by Mathisen *et al.* (1964), Mathiak (1965), and Hopper (1971) (Fig. 5). Seven charges of each size were detonated per block, producing a total of 28 potholes per block (21 potholes of each size in the three blocks combined) (Fig. 4). Each pothole was assigned a letter and number according to the block it occupied, the size of charge, and its position in the row: for example, A254 referred to Block A, 25 pounds, and the fourth pothole from the south.

Pothole Measurements

The surface area and depth of each pothole were determined from measurements taken in March 1968, about 7 mo after blasting. This delay allowed time for initial sloughing-in and settling, and, therefore, measurements were thought to be more meaningful than if taken immediately after blasting. Two diameter measurements were made to the nearest 0.5 ft at the original ground level of each 25- and 50-lb pothole. One measurement was in line with the row and the other at *right* angles to the row. The 75- and 150-lb potholes were shaped like a

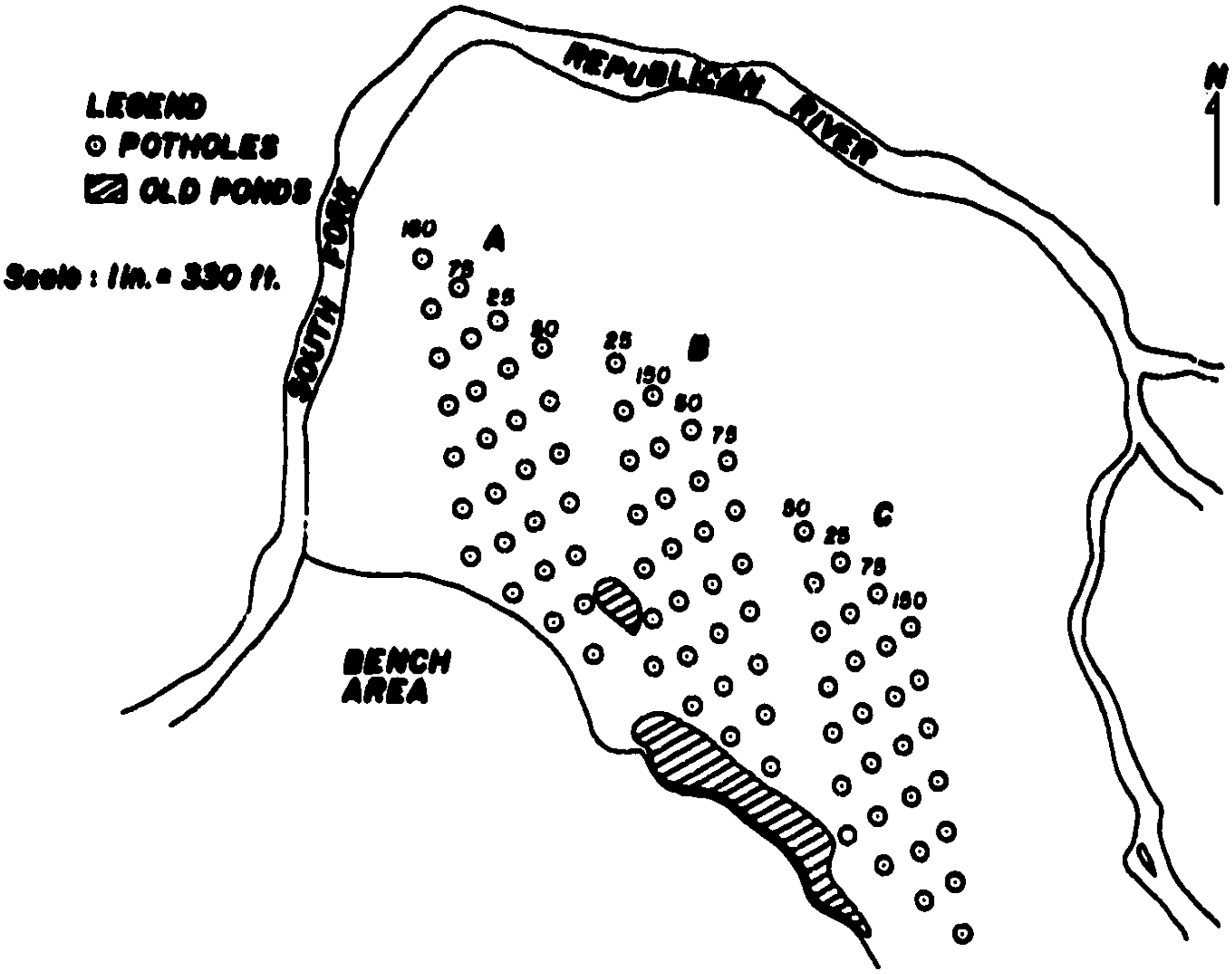

Figure 4—Detailed map of the pothole study area, indicating the position and size of potholes, by study block.

cloverleaf rather than a circle, so the maximum distance across these potholes was considered a biased measurement. Therefore, one measurement was taken from the center edge of each lobe to the opposite side of each of these larger potholes. The resulting measurements of each pothole were averaged to provide the basis for calculating the square feet of surface area.

The depth of each pothole was measured twice during the study, once at the beginning in the spring of 1968 and again at the end of the study in the spring of 1975. Measurements were made with a weighted, calibrated line attached to the end of a 12-ft cane pole. A single depth measurement, to the nearest 1 in., was made of each 25- and 50-lb pothole, but three readings were taken of the 75- and 150-lb potholes, one in each segment of the cloverleaf. The three measurements from each of these latter potholes were then averaged.

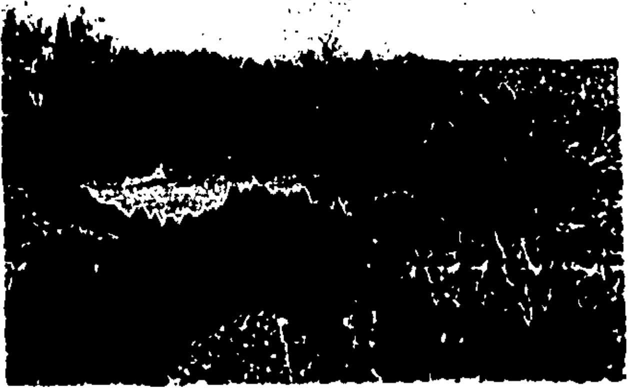

Figure 5—Newly created potholes filled with water shortly after blasting because of the high water table in the marsh. (Photo by R. M. Hopper)

Vegetation Characteristics

The vegetation within 30 ft of the edge of each pothole was mapped, by species, on graph paper during the period July 21-24, 1969. Pacing was done to obtain the approximate area occupied by each species or group of species. Reference to the maps then revealed the relative abundance of each species, by pothole.

Thirty-six potholes were sampled with a garden rake during the periods August 13-15, 1968 and September 9-10, 1970 to determine the presence or absence and relative abundance of submerged aquatic vegetation. The same 36 potholes, 9 of each charge size, constituted the sample in both years. A rope was attached to the end of the rake handle opposite the head to facilitate pulling the rake across each pothole. The rake head was placed teeth-down at points on the edge of each pothole and pulled slowly to the opposite edge. The amount of rake head covered (no. of teeth) by each species of vegetation was recorded after each pass of the rake through the water. The potholes were sampled roughly in proportion to their size, with the following number of passes of the rake being made through each size: 25-lb, 3, 50-lb, 4, 75-lb, 6; 150-lb, 8.

Estimates were made in March and April of 1973 and May of 1975 of the proportion of the surface area of each pothole grown up to emergent vegetation. Two estimates were obtained for each pothole during each year, with the second estimate each year being made without prior reference to the first. An average figure was then calculated for each pothole, by year, and comparisons made by pothole size. Only 69 potholes were still in existence in 1975, and thus they were the only ones used in these comparisons.

Waterfowl Use

Waterfowl use of the potholes was observed in the spring (March-June) during all 5 yrs of field study (1968-1970, 1973, 1975). Summer (July-September) and fall (October-November) observations were conducted during the first 3 yrs only. The potholes were observed 1-4 times during each of the seasons, with each observation period ranging from 1 to 5 days. There were 13 total days of observation in the spring in 1968, 10 in 1969, 20 in 1970, 15 in 1973, and 15 in 1975. Summer observations totaled 6 days in 1968, 4 in 1969, and 9 in 1970. Total days of observation in the fall a[illegible]ted to 7 in 1968, 10 in 1969 and 6 in 1970. The pothole study area was observed for duck use a total of 115 days during the 5 years of field study: 26 days in 1968, 24 in 1969, 35 in 1970, 15 in 1973, and 15 in 1975.

Binoculars and a spotting scope [illegible] watch the potholes from observation points [illegible] at the south edge of the study area (Fig. 1). [illegible] supplied an elevated overlook of the pothole [illegible] readily enabled the observer to spot individual potholes being used by waterfowl.

Observations and counts, lasting at least 1 hr, were made both morning and evening. Morning counts began 0.5 hr before sunrise, and evening counts ended 0.5 hr after sunset. Each block of potholes received an equal number of morning and evening counts. Only one block was watched at a time, except for periods of little activity, when as many as two blocks were observed at one time.

Duck use was recorded by species, sex, and pothole when the birds were observed landing on or leaving a pothole or when they were sitting on or at the edge of a pothole. Each time a duck was observed at a pothole it was counted as one duck visit. Thus, duck-use figures presented in this paper do not represent individual ducks, since many were observed to use more than one pothole.

RESULTS AND DISCUSSION

Fifteen of the original 84 potholes were eliminated during the course of the study, two in 1968 prior to initiation of duck-use observations, four more in 1973, and nine more in 1975. Each of these potholes was dropped from the study for one or more of the following reasons: (1) low water level, (2) muskrat (*Ondatra zibethicus*) activity greatly increased their size, and (3) inadvertent destruction by another habitat development project. Thus, the number of potholes studied was 82 during the period 1968-1970, 78 in 1973, and 69 in 1975.

Pothole Size and Depth

Hopper (1972) presented a detailed discussion regarding the comparative sizes of the 82 potholes produced by the four charge sizes of AN-FO (Table 1). In summary, it was found that (1) average surface areas were consistent from block to block for each charge size, (2) variations occurred within blocks because of differences in soil texture, (3) overlapping of pothole sizes occurred only between 25- and 50-lb charges, (4) average surface areas (sq ft) increased with increase in charge size for all blocks combined, as follows: 25-lb, 201; 50-lb, 293; 75-lb, 570; and 150-lb, 851, (5) doubling the charge size did not double the surface area produced, (6) 75-lb charges produced nearly 100 percent more surface area than 50-lb charges, and (7) the 25- and 75-lb charges were the most efficient in terms of amount of surface area created per pound of AN-FO.

TABLE 1—Surface area comparisons of 82 potholes, by charge size (from Hopper 1972)[a]

Charge size (lbs)	Surface area (sq ft)			
	Range	Mean	Standard deviation	Mean/lb of AN-FO
25	149-276	201	29.7	8.0
50	214-363	293	34.7	5.9
75	459-670	570	55.4	7.6
150	689-1,134	851	103.3	5.7

[a] Twenty-one potholes of each charge size, except the 150-lb size, which had only 19.

Mean depths of the potholes are shown in Table 2, by block and charge size, for 1968 and 1975. Depth comparisons here relate only to the 69 potholes that survived the entire study period. Depths among potholes of a given charge size varied considerably in each block in 1968 and in 1975, just as they did with regard to surface area. Again, soil texture probably contributed greatly to these differences. Mathiak (1965) also noted a wide range in depths, by soil types, for potholes blasted in Wisconsin.

Mean depths of potholes produced by the four charge sizes for all blocks combined varied from 37.1 in. (75-lb) to 42.9 in. (50-lb) in 1968, and from 27.5 in. (150-lb) to 30.4 in. (50-lb) in 1975 (Table 2). These data were subjected to an appropriate analysis of variance involving the three factors (years, blocks, charge sizes); the tests revealed no interaction between years and charge sizes ($P = 0.095$). It appeared, then, that at the beginning of the study, as well as at the end, mean pothole depths were similar among charge sizes. It is also apparent from these tests that there was no overall difference in mean depth of the potholes among the four charge sizes ($P < 0.100$).

Despite similar mean depths of potholes among charge sizes, a considerable amount of depth loss occurred during the 7-yr period between 1968 and 1975 (Table 2). The mean depth for all potholes combined decreased from 38.8 in. in 1968 to 28.8 in. in 1975, a loss of 10.0 in., or about 26 percent in the 7 yrs. This difference between years was highly significant ($P < 0.001$). However, as implied above, the amount of loss was consistent from one charge size to the next. This loss in depth was substantially less than the average of 46 percent loss in depth over a 5-yr period for 21 potholes dynamited by Provost (1948) in Iowa.

Vegetation Characteristics

Mapping of the vegetation surrounding the 82 potholes resulted in the identification of 22 species of plants of obvious abundance on the study area. A list of these plants is shown in Appendix A. Additional species were known to be present, but were considered of minor importance. Grasses and grass-like plants made up over half of the species listed. Most are commonly associated with moist environments such as that provided by the presence of the high water table on the study area.

The most common species of plants associated with the potholes on the study area were common threesquare and sedge, the latter being represented by at least two species (Fig. 6). These were also the most abundant species in the individual blocks and adjacent to each of the four different sizes of potholes. Common spikerush was the only other species that occurred in abundance in all three blocks and adjacent to all four sizes of potholes. Baltic rush was important in all of these categories except the 150-lb pothole size. Three other species, white sweetclover, squirreltail, and broadleaf cattail, were fairly consistent in occurrence by block and charge size but varied in rank of importance.

TABLE 2—Pothole depth measurements, by block and charge size, 1968 and 1976

Charge[a] size (lbs)	Mean depth (in.)								[illegible]
	1968				1976				
	Block A	Block B	Block C	Total	Block A	Block B	Block C	Total	
25	39.6	34.5	38.6	37.6	29.5	26.9	[illegible]	[illegible]	[illegible]
50	41.7	41.8	45.1	42.9	28.5	29.5	33.3	[illegible]	[illegible]
75	36.8	36.6	37.9	37.1	28.1	25.1	29.7	[illegible]	[illegible]
150	32.6	40.3	[illegible]	37.7	26.5	28.0	30.1	[illegible]	[illegible]
Total	37.7	38.3	40.5	38.8	27.6	27.4	31.2	[illegible]	

[a] The sample consisted of 69 potholes, including: 25-lb, 18; 50-lb, 20; 75-lb, [illegible]

Figure 5—Appearance of vegetation around potholes 1 yr after blasting. (Photo by R. M. Hopper)

Figure 7—Submerged and floating-leaved aquatic vegetation became established in many potholes soon after blasting. (Photo by R. M. Hopper)

The first evidence of vegetative growth within the potholes was noted on October 11-12, 1967, only 2 mo after the potholes were blasted. With the benefit of only visual observations, four potholes were found to contain muskgrass (*Chara* spp.) at that time.

The formal sampling procedure produced 189 samples in 36 potholes and found 6 species of submerged aquatic plants during the 2 yrs of vegetation study, 5 in 1968 and 6 in 1970 (Table 3). The first sampling period (August 13-15, 1968) was exactly 1 yr following creation of the potholes, and the second (September 9-10, 1970) was slightly over 3 yrs later. Vegetation was encountered in 31 (86.1%) of the 36 potholes sampled in 1968, and in all but one (97.2%) of the 36 potholes in 1970 (Fig. 7). Frequencies of occurrence, expressed as the percentage of total number of samples (drags) in which a species occurred, are compared in Table 3, by species and year. A higher percentage of samples contained submerged aquatic vegetation in 1970 (92.6) than in 1968 (84.1). Occurrences of longleaf pondweed (*Potamogeton nodosus*), sago pondweed (*P. pectinatus*), and coontail (*Ceratophyllum demersum*) increased in 1970 over 1968, while leafy pondweed *(P. foliosus)*, muskgrass, and horned-pondweed *(Zannichellia palustris)* decreased. This pattern also held true by charge size, except that muskgrass increased in occurrence from 1968 to 1970 in 50-lb potholes and remained stable in 75-lb potholes.

TABLE 3—Comparison of frequency of occurrence of submerged aquatic vegetation among charge sizes, as estimated from 189 samples in 36 potholes, 1968 and 1970

	Frequency of occurrence (%)[a]									
	Charge size (lbs)									
	25		50		75		150		Total	
Species	1968	1970	1968	1970	1968	1970	1968	1970	1968	1970
Ceratophyllum demersum		0	0	5.6	0	7.4	0	23.6	0	12.2
Chara spp.	44.4	33.3	5.6	41.7	55.6	55.6	68.0	16.7	49.2	34.9
Potamogeton foliosus	25.9	3.7	25.0	8.3	53.7	24.1	35.6	13.9	45.0	14.3
Potamogeton nodosus	33.3	44.4	11.1	19.4	31.5	48.1	40.3	45.8	31.2	41.3
Potamogeton pectinatus	0	66.7	44.4	72.2	24.1	72.2	19.4	47.2	22.8	61.9
Zannichellia palustris	7.4	3.7	0	0	18.5	0	0	0	6.3	0.5
Total	77.8	100.0	66.7	91.7	92.6	100.0	88.9	84.7	84.1	92.6

[a] Percentage of total number of samples in which a species occurred.

Densities of the various species of submerged vegetation are compared in Table 4, by charge size. Density, here, refers to the mean number of rake teeth covered by each species of vegetation per sample. All species combined averaged 9.6 teeth covered per sample in 1968 and 15.5 in 1970 for the four charge sizes. Densities more than doubled from 1968 to 1970 for each charge size except the 150-lb size, which yielded similar densities in both years. Individual species showing increases in densities from 1968 to 1970 in all charge sizes included coontail, longleaf pondweed, and sago pondweed, with the greatest increase being by the last species. Decreases were noted for leafy pondweed and horned-pondweed. Muskgrass increased in the three smallest charge sizes, but decreased in the 150-lb potholes.

Invasion of the potholes by emergent vegetation was first noted in July 1969, about 2 yrs after creation of the potholes. At that time, 41 (50%) of the 82 potholes contained some emergent vegetation. In all cases, these stands of emergent vegetation were both sparse and limited in distribution within the potholes. The following six species, listed in descending order of occurrence, were represented: broadleaf cattail, common threesquare, hardstem bulrush (*Scirpus acutus*), common spikerush, Baltic rush, and broadleaf arrowhead (*Sagittaria latifolia*). The first three species listed occurred in 25, 19, and 12 potholes, respectively.

By the spring of 1973, emergent vegetation was present in all potholes, and was well established in over 60 percent, based on the number of potholes that had over 20 percent of their surface areas grown up to emergents. Almost 15 percent of the potholes were completely choked, or nearly so, with an estimated 85-100 percent of their surface areas grown up to emergent vegetation. Thus, in the 4-yr period between 1969 and 1973, emergent vegetation became a dominant factor in plant succession within the potholes. Broadleaf cattail was by far the [illegible] that encroached, occurring in over 75 percent of the potholes. Common threesquare and hardstem bulrush were the only other intruding species of importance.

The situation only 2 [illegible] similar to that in 1973 in most re[illegible] was that the percentage of the [illegible] completely choked, or nearly so, with emergents [illegible] doubled from 1973 to 1975 (15% to 28%). However, [illegible] reduction in the estimated percentages of surf[illegible] grown up to emergents for some potholes from [illegible] 1975 to compensate for the a[illegible] difference [illegible] overall means of these estimates to be comp[illegible] een years. It should be noted, however, that [illegible] estimates of the percentages of surface area [illegible] emergents did little to consider comparative d[illegible] een years, and it was quite likely that higher [illegible] emergents occurred in 1975 than in 1973.

Table 5 gives an indication of [illegible] emergent encroachment in the potholes [illegible] referring to this table that invasion of the p[illegible] emergent vegetation was not restricted by [illegible]. Overall, potholes of one charge size appeared [illegible] about as likely to be invaded as those of any other [illegible]. The range in the percent of surface areas grown up to emergents was also essentially the same (5-90 or 100%) for potholes of each charge size. As noted above, there appeared to be little change in the mean estimates, by charge size and overall, from 1973 to 1975.

TABLE 4–*Density comparisons of submerged aquatic vegetation among charge sizes, as estimated from 189 samples in 36 potholes, 1968 and 1970*

	Mean density[a]									
	Charge size (lb)									
	25		50		75		150		Total	
Species	1968	1970	1968	1970	1968	1970	1968	1970	1968	1970
Ceratophyllum demersum	0	0	0	0.3	0	0.3	0	2.4	0	1.1
Chara spp.	1.9	3.0	0.2	2.7	3.1	5.2	6.1	1.3	3.5	2.9
Potamogeton foliosus	2.1	0.1	1.6	0.9	3.6	3.0	4.0	0.6	3.1	1.2
Potamogeton nodosus	2.0	3.5	0.4	1.7	1.3	4.5	1.6	3.1	1.4	3.3
Potamogeton pectinatus	0	7.4	2.7	7.8	1.1	7.5	1.4	6.0	1.3	7.0
Zannichellia palustris	0.2	0.2	0	0	1.0	0	0	0	0.3	T[b]
Total	6.2	14.2	4.9	13.4	10.1	20.5	13.1	13.4	[illegible]	15.5

[a] Average number of rake teeth covered per sample.

[b] Less than 0.1.

TABLE 5—Extent of invasion of 69 potholes by emergent vegetation, according to charge size, 1973 and 1975

Charge size (lbs)	Mean percent of pothole surface area estimated to be grown up to emergents	
	1973	1975
25	51.4	56.4
50	47.1	42.5
75	42.6	49.4
150	44.2	44.7
Total	45.1	48.2

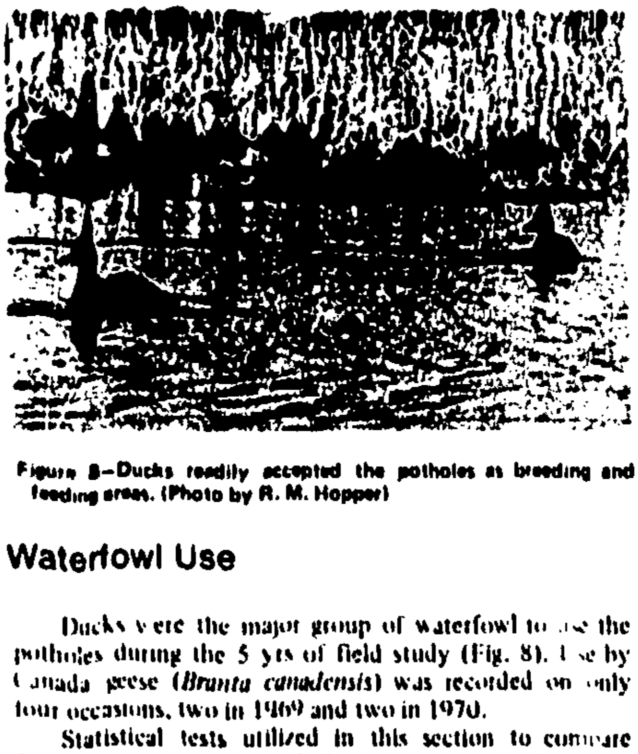

Figure 8—Ducks readily accepted the potholes as breeding and feeding areas. (Photo by R. M. Hopper)

Waterfowl Use

Ducks were the major group of waterfowl to use the potholes during the 5 yrs of field study (Fig. 8). Use by Canada geese (*Branta canadensis*) was recorded on only four occasions, two in 1969 and two in 1970.

Statistical tests utilized in this section to compare duck use among years and charge sizes were applied only to data for the 69 potholes that survived the entire study. However, when statistical tests were not of concern, data from all potholes available during each year were included to document study efforts.

Hours of observation and total amount of use

Nearly 550 hrs were spent watching the potholes during the 5 yrs of observation, resulting in a recorded total of 1,703 duck-visits (Table 6). The total number of hours expended on each block varied considerably by year and for all years combined. Duration of observations was much greater in each of the first 3 yrs than in either 1973 or 1975, primarily because spring, summer, and fall observations were conducted in the former years, while only spring counts were made in the last 2 yrs. The quantity of duck use shown in Table 6 is not comparable among blocks or years because of these annual variations in observing time and number of potholes.

Seventy-nine of the 82 potholes (96.3%) were used at least once by ducks during observation periods. All 75-lb and 150-lb potholes were used, while not a single duck-visit was recorded for one 25-lb pothole (B251) and two 50-lb potholes (A502 and B501). However, two of these potholes (B251 and B501) were not available to receive use during the last year of observations. Nevertheless, over 90 percent of the potholes created by each charge size were visited one or more times.

There was a general increase in the number and percentage of potholes used by ducks as the size of charge or pothole size increased, for individual years and for all years combined (Table 7). This pattern was also apparent in regard to the number and percentage of total duck-visits recorded (Table 8). The only departures from this trend occurred in 1968 when (1) a higher percentage of potholes blasted with 50- and 75-lb charges were used than holes produced by 150-lb charges (Table 7), and (2) potholes created by 75-lb charges received a greater proportion of the total duck-visits than those from 150-lb charges (Table 8). The figures in Table 8 were not adjusted for differences in the number of potholes of each charge size. Had such adjustments been made, the number and percentage of total duck-visits observed would have been even greater for the 75- and 150-lb potholes because of smaller numbers of potholes of these two charge sizes, especially in 1973 and 1975.

TABLE 6—Duration of observations and duck use of 82 potholes, by block and year, all seasons

Block	No. of potholes[a]	1968		1969		1970		1973		1975		Total	
		Hours of observation	Duck visits	Hours of observation	Duck visits	Hours of observation	Duck visits	Hours of observation	Duck visits	Hours of observation	Duck visits	Hours of observation	Duck visits
A	27	46.3	92	34.0	64	46.8	241	23.7	115	24.0	125	164.7	619
B	29	37.3	[illegible]	32.3	53	56.1	215	26.0	77	23.0	124	197.3	656
C	27	47.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21.0	[illegible]	[illegible]	[illegible]
Total	82	130.8	302	91.3	137	160.5	[illegible]	67.5	207	68.0	266	[illegible]	1,703

[a] Unadjusted for differences in the number of potholes of each charge size. There were only 26 potholes in Block B in 1973, 21 in Block C in 1973, and 19 in Block C in 1975, the total amounting to 74 potholes in 1973 and [illegible] potholes in 1975.

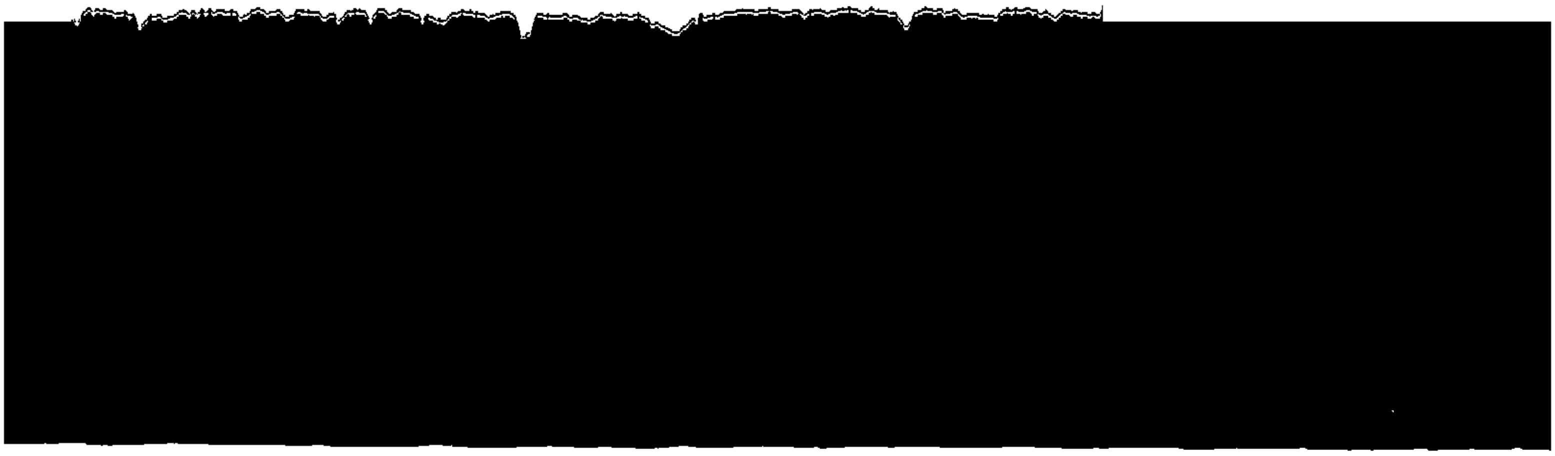

TABLE 7—Number and percentage of 82 potholes used by ducks, according to AN—FO charge size and year, all blocks combined, all seasons

Charge size (lbs)	No. of potholes[a]	1968		1969		1970		1973		1975		Mean	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
25	21	14	66.7	4	19.0	14	66.7	4	19.0	5	27.8	8.[illegible]	40.2
50	21	18	85.7	8	38.1	15	71.4	7	33.3	11	55.0	11.8	56.7
75	21	19	90.5	15	71.4	18	85.7	11	57.9	11	68.8	14.8	75.5
150	19	15	78.9	15	78.9	19	100.0	13	76.5	11	73.3	14.6	82.0
Total	82	66	80.5	42	51.2	66	80.5	35	44.9	38	55.1	49.4	62.8

[a] There were only 19 75-lb potholes and 17 150-lb potholes in 1973. In 1975, the number of potholes per charge size was: 25-lb, 18; 50-lb, 20; 75-lb, 16; 150-lb, 15.

TABLE 8—Comparison of number and percent of duck-visits on 82 potholes, by charge size and year for all blocks combined, all seasons

Charge size (lbs)	1968		1969		1970		1973		1975		Total	
	No. of duck visits[a]	%	No. of duck visits	%	No. of duck visits	%	No. of duck visits	%	No. of duck visits	%	No. of duck visits	%
25	59	11.8	8	4.1	47	8.9	16	7.7	10	3.8	140	8.2
50	80	15.9	31	15.7	49	9.2	21	10.2	45	16.9	226	13.3
75	201	40.0	69	35.0	160	30.1	48	23.2	84	31.6	562	33.0
150	162	32.3	89	45.2	275	51.8	122	58.9	127	47.7	775	45.5
Total	502	100.0	197	100.0	531	100.0	207	100.0	266	100.0	1,703	100.0

[a] Unadjusted for differences in the number of potholes of each charge size.

Use, by species

Twelve species of ducks, seven dabblers and five divers, were observed using potholes during observations (Table 9). Mallards (*Anas platyrhynchos*), the most common species in all seasons, contributed 991 (58.2 percent) of the 1,703 visits (Fig. 9). Gadwalls (*Anas strepera*) accounted for 161 (9.4 percent) visits, mainly as spring migrants. Blue-winged teals (*Anas discors*), the second most important breeding species here, were next, with 141 visits, or 8.3 percent of the total. Diving-duck use was dominated by lesser scaups (*Aythya affinis*), with 109 visits, or 6.4 percent of the total.

There was a marked preference, by species, for the larger potholes, or those created by the 75- and 150-lb charge sizes (Table 9). For all species combined, there appeared to be an increase in preference with an increase in the size of charge (pothole size). Individually, mallards, American wigeons (*Anas americana*), blue-winged teals, and northern shovelers (*Anas spatula*) seemed more partial to holes from 150-lb charges. Green-winged teals (*Anas carolinensis*) frequented holes resulting from 75-lb charges more than any other size, while gadwalls and lesser scaups utilized potholes created by 75- and 150-lb charges about equally. Sample sizes for the remaining species were insufficient to indicate preferences for potholes produced by any particular charge size. The two groups of ducks, dabblers and divers, exhibited similar preferences for potholes of the four size categories (Table 9).

Season of use

Observations of duck use during spring, summer, and fall of the first 3 yrs led to the conclusion that most use of the potholes occurred in the spring (Table 10). Spring observations, totaling 221.9 hours for all blocks, yielded 1,210 duck-visits (98.4% of total), or an average of 5.4 duck-visits per hour. Summer and fall counts were much lower, averaging only 0.04 and 0.15 visits per hour.

TABLE 9—Number of duck-visits, by species and percentage occurring in each AN—FO charge size, for 82 potholes, all blocks and years combined, 1968-1970, 1973, and 1975, all seasons

Species	No. of duck visits	Percent of total	Percent of total in each charge size[a]			
			25	50	75	150
Mallard	991	58.2	8.2	15.2	32.4	44.2
Gadwall	161	9.4	5.6	14.3	37.3	42.8
American wigeon	39	2.3	0	15.4	12.8	71.8
Green-winged teal	32	1.9	15.6	0	53.1	31.2
Blue-winged teal	141	8.3	9.9	5.0	39.0	46.1
Unidentified teal	10	0.6	30.0	0	50.0	20.0
Northern shoveler	102	6.0	11.8	13.7	25.5	49.0
Pintail	2	0.1	0	0	50.0	50.0
Redhead	2	0.1	0	0	100.0	0
Canvasback	18	1.1	0	0	33.3	66.7
Lesser scaup	109	6.4	4.6	14.7	38.5	42.2
Ring-necked duck	9	0.5	0	11.1	11.1	77.8
Bufflehead	1	0.1	0	0	0	100.0
Unidentified diver	34	2.0	23.5	5.9	20.6	50.0
Unidentified duck	52	3.0	5.8	11.5	26.9	55.8
Total	1,703	100.0	8.2	13.3	33.0	45.5
All dabblers	1,478	89.5	8.4	13.6	33.1	44.8
All divers	173	10.5	7.5	11.0	33.5	48.0

[a] Unadjusted for differences in the number of potholes of each charge size.

TABLE 10—Seasonal duck use of 82 potholes, all blocks combined, during the first 3 yrs (1968-1970)

Season	No. of hours observed	No. of duck visits	Mean no. of duck visits/hr
Spring (March-June)	221.9	1,210	5.45
Summer (July-September)	76.4	3	0.04
Fall (October-November)	115.2	17	0.1
Total	413.5	1,230	2.97

respectively. Thus, it was decided to eliminate summer and fall observations during the last 2 yrs of the study, and further evaluations of duck use in this section were restricted to data from spring observations only.

The major response to the potholes in the spring was by migrant birds and breeding pairs. Mallards, especially, established and defended territories that included one or more potholes (Fig. 7). The study area offered seclusion and territorial space for pairs in the form of small water areas. At Delta, Manitoba, Hoffman (1970) also found that the highest use of blasted ponds occurred during the spring and early summer.

Use, by year and charge size

In order to make the duck-use observations comparable by year and charge size, it was necessary to compute use in terms of the number of duck-visits per pothole per hour of observation. This avoided the problem cited earlier of varying numbers of hours of observation by year, as well as varying numbers of potholes by year and charge size. Only spring observations and only the 69 potholes still in existence in 1975 were used in making these comparisons. The specific data that apply to this season and number of potholes are shown in Table 11.

TABLE 11—Number of hours of observation and duck use of 69 potholes still in existence in 1975, by year, block, and charge size (Spring only)

Year and block	Hours of observation	[illegible]				
		25	50	[illegible]	[illegible]	[illegible]
1968						
A	29.5	3	26	[illegible]	[illegible]	[illegible]
B	38.0	11	[illegible]	[illegible]	[illegible]	[illegible]
C	29.9	10	[illegible]	[illegible]	[illegible]	[illegible]
Totals	97.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1969						
A	16.2	0	4	[illegible]	[illegible]	[illegible]
B	17.6	3	12	[illegible]	[illegible]	[illegible]
C	11.2	5	11	[illegible]	[illegible]	[illegible]
Totals	45.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1970						
A	26.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
B	26.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C	26.3	[illegible]	[illegible]	[illegible]	25	[illegible]
Totals	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1973						
A	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C	16.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Totals	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1975						
A	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Totals	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
All years						
A	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Totals	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Number of potholes						
A		[illegible]	[illegible]	[illegible]	[illegible]	
B		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C				[illegible]	[illegible]	[illegible]
Total		[illegible]		[illegible]	[illegible]	[illegible]

Figure 9—The mallard was the most common species of waterfowl that utilized the potholes. (Photo by R. A. Ryder)

Table 12 presents the mean number of duck visits per pothole per hour of observation for each year, by block and charge size, as calculated from the base data in Table 11. The mean number of duck-visits per pothole per hour varied, by year, from 0.12 in 1973 to 0.27 in 1970 for all blocks and charge sizes combined (Table 12). An analysis of variance was performed on the duck visits per pothole per hour involving three years, blocks, and charge sizes; the difference among years was significant ($P < 0.005$). The studentized range method (Dixon and Massey 1969) was used to find what years were different from the others, and revealed that in 1970 the potholes received significantly more duck use than they did in either 1973 or 1975, but that no other differences were detected among years. An obvious conclusion might be that the attractiveness of the pothole study area declined after 1970; however, such a conclusion must be viewed with caution. Differences in duck use among years simply may have been a reflection of annual fluctuations in numbers of ducks in the vicinity

[redacted]

of the study area or of inconsistent timing of observations with peak periods of duck activity from year to year. Thus, while it is likely that deteriorating habitat conditions had some effect in reducing duck use of the potholes over the period of study, it is difficult to know the extent of this relationship.

The major concern in this study was the comparison of the four sizes of potholes in regard to duck use. This led to a test of the null hypothesis that there was no difference in the mean number of duck visits received per pothole per hour of observation among potholes produced by each of the four charge sizes of AN-FO. Reference to the data in Table 12 shows that the dominant trend was an increase in duck use with an increase in charge size or surface area, for all blocks and years combined. The corresponding null hypothesis of no difference in duck use by charge size was rejected (P < 0.01), thus providing evidence that there was a highly significant difference in duck use of potholes among the four charge sizes. The studentized range method (Dixon and Massey 1969) was employed to find out where this difference occurred, and revealed that (1) potholes from both the 75- and 150-lb charge sizes received significantly more duck use than those from either the 25- or 50-lb sizes, (2) 150-lb potholes accounted for significantly more use than 75-lb potholes, and (3) no significant difference was indicated between 25- and 50-lb potholes. The differences in duck use among pothole sizes were generally consistent from year to year (P = 0.095).

TABLE 12—Number of duck-visits per pothole per hour of observation, by year, block, and charge size for 69 potholes (Spring only)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]						
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
150	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mean	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]						
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
150	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mean	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]						
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
150	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mean	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]						
25	[illegible]	[illegible]	[illegible]	.030	[illegible]	.055
50	[illegible]	[illegible]	[illegible]	[illegible]	.101	[illegible]
75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
150	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mean	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Other workers have also found a direct relationship between the size of both natural and artificial ponds and duck use during the spring period (Smith 1953, Berg 1956; Evans and Black 1956; Lokemoen 1973). They reported that although most use occurred on larger ponds, the smallest ponds received the greatest use per acre of surface area. In the present study, most of the use was on the larger potholes and these potholes also attracted the greatest use per acre. However, in the studies cited above, the ponds involved were generally much larger in size than those blasted as part of this study. This suggests that the findings noted above, indicating that the smallest areas received the heaviest use per acre, may apply only to ponds above a certain size.

Duck use in relation to pothole cost and size

Analysis of the data from the first 3 yrs of observations (1969-1970) suggested that, of the four charge sizes tested, the 75-lb charge of AN-FO created the most efficient potholes in terms of duck use in relation to pothole cost and size (Hopper 1972). This size yielded the lowest mean cost per duck-visit received and also the highest mean number of duck-visits per 100 sq ft of surface area. The 150-lb charge was the next most efficient size in this regard, and it was concluded that over a longer period of time (5-10 yrs or more) potholes from this charge size may have a longer useful life than those from the 75-lb size, thereby eventually equalling or exceeding the latter in duck use efficiency.

The updated analysis covering all 5 yrs of duck-use observations (7-yr period) did produce the change in efficiency between 75- and 150-lb potholes suggested above (Table 13). For whatever reason, the 150-lb potholes received considerably more duck use during the last 2 yrs of observations (1973 and 1975) than the 75-lb potholes to account for this reversal in efficiency. The 150-lb size produced a mean cost per duck visit of $0.23 and a mean value of 5.5 duck-visits per 100 sq ft of surface area, compared to figures of $0.40 and 5.1, respectively, for the 75-lb size. It should be noted that all figures in Table 13 are comparative rather than actual, since they represent duck use only during observation periods. Also, these data apply only to the 69 potholes that still existed at the end of the study in 1975.

In the earlier analysis involving only the first 3 yrs of observation, the 25-lb charge was indicated to be slightly more efficient than the 50-lb size, in terms of duck use. The updated analysis resulted in a change in this relationship, just as it did between the 75- and 150-lb sizes (Table 13). Thus, the conclusion based on the final analysis is that the efficiency of the charge sizes in terms of duck use, both from the cost and surface-area standpoints, increased with an increase in charge size.

TABLE 13—Duck use in relation to pothole cost and size for 69 potholes, 1968-1970, 1973 and 1975 (Spring only)

Charge size (lbs)	No. of duck-visits	Mean cost per duck-visit	Mean no. of duck-visits per 100 ft² of surface area
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

Pothole Longevity and Duck Use in Relation to Vegetation Changes

While the potholes may exist physically for many years, we must look at the basic purpose for creating them in the first place to develop and maintain high-quality waterfowl habitat. With the maturation and constantly changing character of the potholes, over time, the job of maintaining wetland values becomes one of arresting or setting back plant succession to a stage that is most useful to waterfowl (Singleton 1965, Sanderson and Bellrose 1969). If the potholes lose their attractiveness to waterfowl after a period of time because of loss of depth, encroachment of emergents, or for some other reason their usefulness as waterfowl habitat has ended or been seriously curtailed and the manager can conclude that they have reached their life expectancy. Thus, it is important to distinguish between "physical" longevity and "management" longevity, the latter being related to the original purpose of particular habitat developments.

The major factor influencing the physical longevity of open-water areas is the natural process known as "succession". "Hydrarch succession" starts in open water wherever vegetation can become established and progresses in response to any environmental change that decreases the water depth or saturation and improves aeration in the soil of the habitat (Oosting 1956). The trend is, therefore, from an aquatic toward a terrestrial habitat, with pioneering vascular plants being submerged aquatics. In the case of the pothole study area, normal succession was temporarily disrupted on specific sites of this shallow marsh through the creation of small open-water areas in 1967. The tendency was then for normal succession to again start in the earlier stages and gradually progress toward the "closing-in" of the marsh through the invasion of the open-water areas by emergent vegetation (Fig. 10).

The width or diameter of the potholes, regardless of charge size, did not change during the course of the study. This was due to the characteristic steep sides of the potholes and the stabilization of the banks through the natural establishment of vegetation. The potholes did, however, become shallower over the period of study from 1968 to 1975, losing, as noted earlier, an average of 10 in. of depth during the 7-yr period for all potholes combined (Table 2). There was no evidence of a differential loss, by charge size, or of a difference in mean depth of the potholes, by charge size, at the termination of the study in 1975. Thus, with similar mean depths, the potholes of all four charge sizes were invaded by emergent vegetation on a nearly equal basis (Table 5).

Duck use of the potholes of each charge size decreased during the last 2 yrs of observations (1973 and 1975), compared to that recorded during the first 3 yrs (1968-1970) (Table 12). This decrease may have been due to a decline in the attractiveness of the potholes to ducks, or it could simply have been caused by a reduction in the number of ducks available to use the area in 1973 and 1975. There is evidence that the former explanation had some influence in decreasing duck use of the potholes in these last 2 yrs. The number of potholes used at least once decreased from 69 during 1968-1970 to only 18 during 1973 and 1975 combined, suggesting that for some reason a high proportion of the potholes were avoided in the latter 2 yrs (Table 14). In Iowa, Provost (1948) noted that as clearings blasted with dynamite aged and the banks assumed the character of the surrounding marsh, they lost their attractiveness to the major species of puddle ducks using his study area.

TABLE 14—Duck use of 69 potholes, according to charge size during early and late years of the study (Spring observations)

Charge size (lbs)	No. of potholes used	1968-70 %	% of duck-visits	No. of potholes used	1973 and 1975 %	% of duck-visits
25	19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
150	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The data in Table 14 indicate that the 25- and 50-lb potholes were avoided to a much greater extent than potholes of the two larger charge sizes. Also, the proportion of total duck-visits declined for potholes of all charge sizes except the 150-lb size from the former to the latter period. This may have resulted from a reduction in attractiveness of potholes of the three smaller sizes, with a corresponding shift of use to the apparently more attractive 150-lb size. This doesn't mean that the 150-lb potholes didn't lose some of their attractiveness during the course of the study, but simply indicates that they were more attractive than potholes of the other three charge sizes.

A direct relationship between charge size and amount of surface area of water created has already been shown—an increase in surface area with a corresponding increase in charge size (Table 1). Likewise, a direct relationship existed between duck use and charge size—an increase in duck use with an increase in charge size or surface area (Table 12). Surface area and open-water area were synonymous during the first 3 yrs of study, before emergent vegetation became established in the potholes. Invasion of the potholes by emergents during the later years did not change the surface areas (total water areas), but did decrease the size of the open-water areas. Thus, while duck use was related to pothole size, the size of the open-water area may

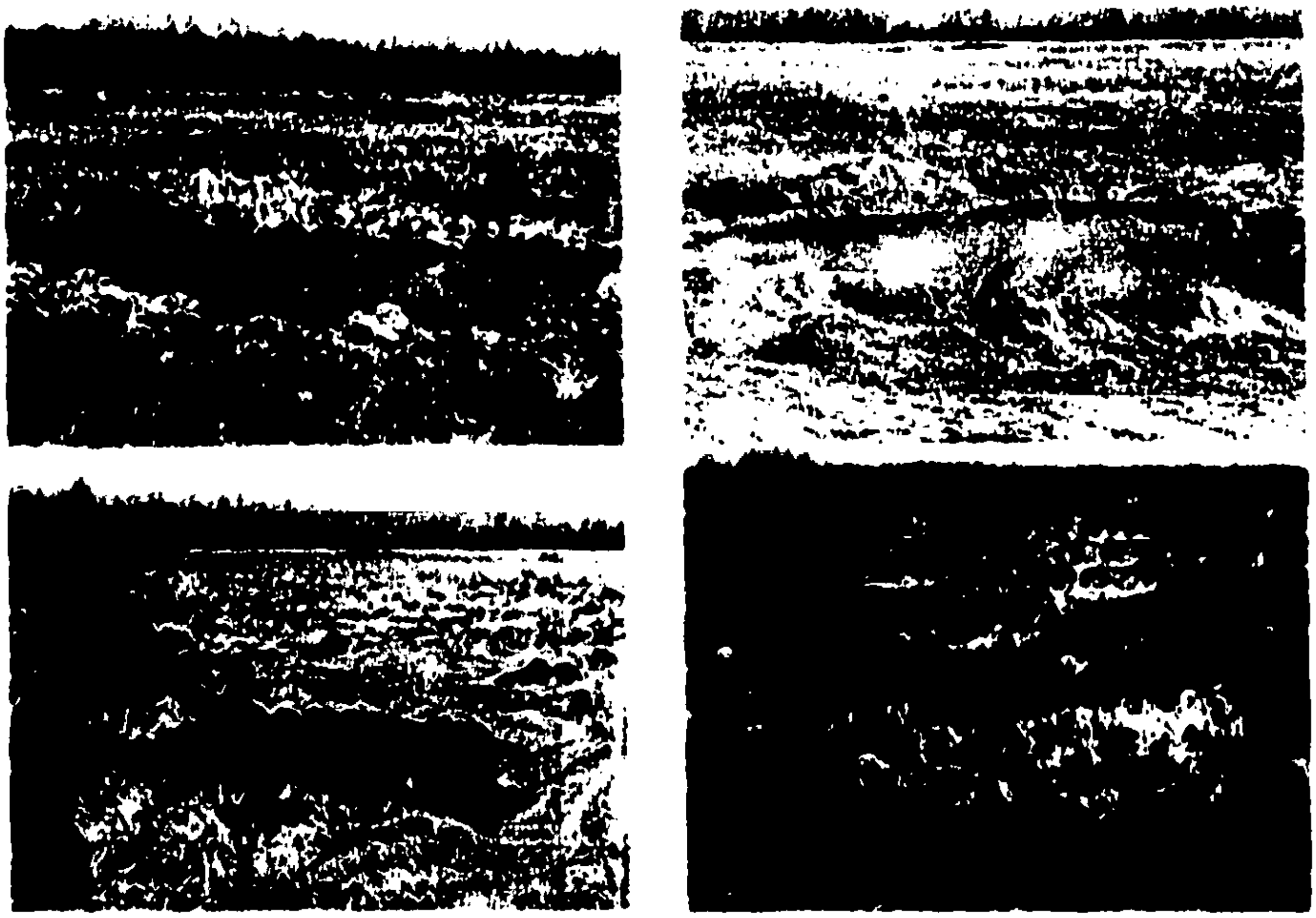

Figure 10—Successive invasion of the 150-lb. pothole (A1502) by emergent vegetation during the course of the study: 1968 (upper left), 1970 (upper right), 1973 (lower left), and 1975 (lower right). All photos taken in April of respective years. (Photos by R. M. Hopper)

have had a greater influence in determining duck use than did the size of the overall surface area. The relationship of duck use and open-water area and encroachment by emergent vegetation is examined in the following paragraphs.

The number of duck-visits per pothole was compared, by charge size, according to four categories of estimated percentages of surface areas of potholes grown up to emergents (Table 15). A decrease in use was noted with an increase in emergent coverage for potholes of every charge size, except for the 50-lb potholes under the 51-75 percent category. Since open water was the portion of the surface area *not* grown up to emergents, it can also be stated that duck use increased with an increase in the proportion of the pothole surface areas consisting of open water. The attractiveness of the potholes, as indicated by a dramatic decline in duck use, was apparently greatly reduced after more than 25 percent of their surface areas became covered with emergents. Duck use was practically non-existent after *open water was reduced to less than 25 percent of the* original surface areas of the potholes.

TABLE 15—Duck use in relation to the invasion of potholes by emergent vegetation, Spring 1975

Charge size (lbs)	Mean number of duck visits per pothole: Percent of pothole surface area grown up to emergents 0-25	26-50	51-75	76-100	Total
25	1.33	1.00	-	0.0	0.55
50	4.33	0.67	1.00	0.29	2.25
75	10.20	5.25	2.11	0.0	4.96
150	14.63	5.67	2.00	0.60	8.20
Total	7.65	3.50	1.71	0.33	3.72

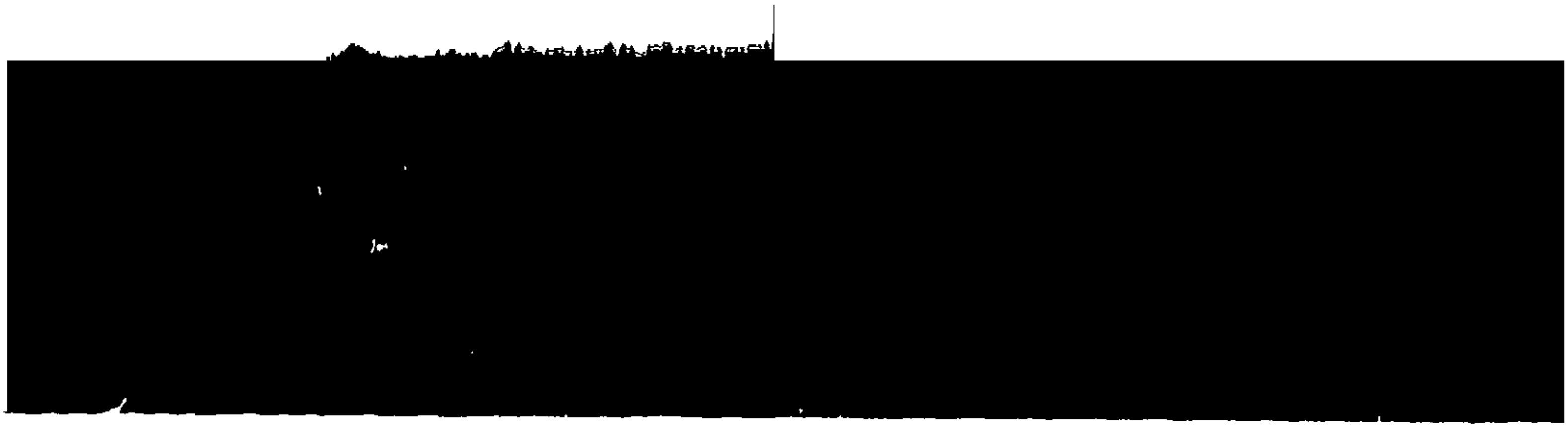

TABLE 16—Correlation analysis of duck use and emergent vegetation coverage for 69 potholes in 1975

Charge size (lbs)	Number of potholes	Mean percent of pothole surface area grown up to emergents	Mean number of duck visits per pothole	r	P	t
25	18	50.39	0.55	-0.642	[illegible]	[illegible]
50	20	42.50	2.25	-0.496	[illegible]	[illegible]
75	16	49.38	4.94	-0.773	[illegible]	[illegible]
150	15	46.67	8.20	-0.730	[illegible]	[illegible]
Total	69	45.19	3.72	[illegible]	[illegible]	[illegible]

A correlation analysis was made on duck use and percent emergent coverage to obtain a statistical measure of the relationship (Table 16). Correlation coefficients (r) ranged from -0.496 for 50-lb potholes to -0.773 for 75-lb potholes, sufficiently large in each case to result in the rejection of the null hypothesis of no correlation between the two variables (P < 0.05 - < 0.01). Thus, duck use and percent emergent coverage of the potholes were not independent, but rather were negatively correlated for potholes of each charge size. This supports the earlier conclusion that duck use decreased as the percent of pothole surface area grown up to emergents increased.

The r^2 values in Table 16 indicate the amount of the variation in duck use accounted for by the percent emergent coverage. 41.2 percent of the variation in the number of duck-visits received by 25-lb potholes was associated with the percent coverage by emergent vegetation. Thus, the encroachment of emergents appears to be a major factor limiting duck use of the potholes of each charge size, and it appeared to have greater impact on use of the 75- and 150-lb potholes than it did on potholes of the two smaller charge sizes. Provost (1948) concluded that if dynamited potholes in Iowa were to continue to be of value to ducks, their banks must stay high and dry and their water area must remain free of emergent vegetation. Studies in South Dakota by Evans and Black (1956) showed that, normally, potholes with excessively dense vegetation were used very little, and that those with sparse cover or no vegetation were clearly preferred by breeding pairs of ducks.

Invasion of the potholes by emergent vegetation was effective in reducing the size of the open-water areas, and thus was the major factor believed to determine the quantity of duck use received by the potholes and, ultimately, their "management" longevity (Fig. 10). The size of the open-water areas, as determined by charge size, was directly related to the amount of duck use received during the first 3 yrs of the study, prior to establishment of emergents in the potholes (Table 12). This relationship also held true after emergent encroachment, as evidenced by a comparison of duck use in 1975 with size of open-water areas, without reference to charge size (Table 17). No use occurred on the 13 potholes with only 0-50 sq ft of open-water area available, while use progressively increased as the size of the open-water area increased. Use rose considerably after the size of the open-water areas of the potholes reached the 401-600 sq ft category. It is further noted that this large jump in use occurred in an open-water category well above the original mean sizes of both the 25- and 50-lb potholes. Thus, preference for the potholes by ducks appeared to be related to the size of the open-water area, which, in later years of the study, was determined by the amount of encroachment by emergent vegetation. According to Weller (1975), the size of open areas in cattails influenced bird use, with well-interspersed pools larger than 30 ft in diameter preferred.

TABLE 17—Comparison of duck use according to size categories of open-water areas, 1975

Open-water area (sq ft)	Number of potholes	Mean number of duck visits per pothole
0-50	13	0.0
51-100	4	0.33
101-200	27	1.35
201-400	15	3.88
401-600	7	9.71
601-900	3	15.60
Total	69	3.72

The mean proportion of open-water area [illegible] emergent invasion between 1968 and 1975 was fairly consistent for potholes of all four charge sizes (Table 18). This affected the attractiveness of potholes of the smaller charge sizes (25- and 50-lb) more than the larger sizes because they were more limited initially in amount of open water. Even though the 150-lb potholes had lost an average of 50 percent of their open-water area by 1975, for example, they still maintained an open-water area over twice as large (463 sq ft) as that originally found in the 25-lb potholes (212 sq ft) in 1968. This simply means that, on the average, the larger the charge size used to produce a pothole, the larger the size of the open-water area it maintained during the 7-yr period between 1968 and 1975. From this standpoint, then, "management" longevity of the potholes increased with an increase in charge size, with the 150-lb potholes remaining more attractive for a longer period of time than potholes of the other charge sizes.

TABLE 18—Loss of open-water area from 1968 to 1975 as a result of invasion of potholes by emergent vegetation

Charge size (lbs)	Number of potholes	Mean open-water area (sq ft) 1968	1975	Percent of open-water area lost
25	18	212	88	58.5
50	20	453	169	62.7
75	16	561	280	50.1
150	15	845	463	45.0
Total	69	[illegible]	218	47.4

The "management" longevity, or effective life, of the 25- and 50-lb potholes was judged to be a maximum of 6-8 yrs under the conditions that existed on the Bonny Reservoir study area. The 50-lb potholes appeared to remain effective in attracting ducks for a somewhat longer period than the 25-lb potholes. Only 26 percent of the 25-lb potholes and 55 percent of the 50-lb potholes were used during the last year of study (1975), representing large reductions from the earlier years (Table 7). Also, the mean open-water area had been reduced to only 88 and 169 sq ft, respectively, for the 25- and 50-lb potholes upon termination of the study in 1975 (Table 18). Duck use on open-water areas of these sizes was extremely low compared to that on larger open waters (Table 17).

The 75- and 150-lb potholes remained effective longer than the two smaller sizes in attracting duck use, with most potholes of these sizes maintaining a "management" longevity of over 8 yrs. Nearly 70 percent of the 75-lb potholes and 73 percent of the 150-lb potholes were used in 1975, after about 8 yrs of existence (Table 7). While potholes of these two charge sizes lost a large proportion of their open water during the course of the study, they still maintained open-water areas large enough to attract significant amounts of duck use. However, the 150-lb potholes had the greatest mean area of open water (Table 18) and received by far the most duck use in 1975 and in all years combined. For these reasons, the 150-lb potholes would probably exceed the 75-lb potholes in "management" longevity, but the study did not progress long enough to confirm this possible difference. Provost (1948) thought about 10 yrs was the limit of effective life for openings blasted with dynamite in Iowa.

Water depth appears to be an important element determining the longevity of blasted potholes because of its influence in controlling the invasion of emergent vegetation. Nelson (1954) reported that water depth was one of the *major factors restricting development of marsh plants* at Ogden Bay Refuge in Utah, but that hardstem bulrush and cattail can spread by underground rhizomes into waters up to 30 in. deep. Linde *et al.* (1976) noted that in Wisconsin cattail seemed to thin out when water depths reached 30 in. Potholes in the present study averaged only 28.8 in. deep at the end of the study in 1975 and emergents had become well established, indicating that sufficient pothole depth was not maintained throughout the study period to discourage this invasion.

The objective, then, becomes one of maintaining as much open water as possible in blasted openings, and Provost (1948) felt that depth was the key to fulfilling this objective. *However, it should be emphasized that depth* is determined by (1) soil types and (2) water levels in the marsh (Strohmeyer and Fredrickson 1967). Considering these points, Mathiak (1965) recommended the larger charge sizes in AN-FO blasting because they improved the chances for increased depth and diameter of the potholes, which he also believed would increase their longevity.

Cattail control offers some opportunity to increase the "useful life" of artificially created potholes. Although cattail is persistent, spreads aggressively, and has a great reproductive potential, it does have its weaknesses which can be used to advantage in control of this emergent species (Linde *et al.* 1976). Because of relatively small surface areas of water involved, a cattail control program could easily be implemented on potholes blasted with AN-FO. Several mechanical and chemical methods have been developed for reducing or eliminating cattail growth (Martin *et al.* 1957; Nelson and Dietz 1966, Linde 19

RECOMMENDATIONS

1. The objectives of pothole blasting, from a management standpoint, should be closely evaluated before undertaking such a program on public or private lands. The greatest value of small potholes seems to be in providing territories for breeding ducks, distributing breeding pairs throughout the marsh, and in supplying feeding areas for ducks during the spring. Their existence can result in increased duck production and overall use on marsh areas previously having little or no open water available. They appear to offer little potential for hunting, so they should not be viewed as a method for developing harvest habitat.

2. Close adherence to the following basic guidelines will increase the probability of creating potholes with the greatest possible management longevity.

   a. Select marshes with heavier mineral soils (clays and loams) and with stable water levels at or within a few inches of the soil surface. Potholes blasted in sandy or peat soils are not normally of acceptable depth. Potholes with high stable water levels discourage growth of emergent vegetation and are more attractive to ducks.

   b. Charge holes should be at least 2.5 ft deep, with a depth of about 4 ft being preferred. A major concern is that the top of the charge be at least 1 ft below the soil surface. The diameter of the hole should be just large enough to accommodate the bag of AN-FO.

   c. Remove most of the water from the charge holes to prevent the bags of AN-FO from floating and to insure a solid mud pack around and above the charges. Following placement of the charges, use only the heavier mineral soils and stem or pack as uniformly as possible by hand and foot. Detonation should immediately follow placement and stemming to prevent water from reaching the AN-FO mixture in significant amounts.

3. Of the four charge sizes of AN-FO tested in this study, the 150-lb size is recommended for best results in terms of cost per unit of duck use, duck use per unit of surface area, and "management" longevity.

4. Control of cattails and other emergent vegetation should be considered as a means of maintaining the attractiveness of blasted potholes to waterfowl, thereby increasing their "management" longevity. Various mechanical and chemical means of emergent control are available to the manager, but use of the chemical Dalapon or cutting of the stems at least 3 in below the water surface during mid-summer seem to have the greatest application to potholes.

5. Additional research is needed, as follows:

   a. Test other charge sizes and spacing of multiple charges.

   b. Determine the proper density and distribution of potholes within a marsh for maximum waterfowl use.

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APPENDIX A

Major Plants Found Adjacent to Potholes[a]

Botanical name	Common name
Agropyron desertorum	Crested wheatgrass
Apocynum medium	Intermediate dogbane
Asclepias incarnata	Swamp milkweed
A. speciosa	Showy milkweed
Bromus tectorum	Cheatgrass brome
Carex spp.	Sedge
Cicuta douglasii	Douglas waterhemlock
Distichlis spicata	Inland saltgrass
Elymus canadensis	Canada wildrye
Eleocharis macrostachya	Common spikerush
Equisetum kansanum	Kansas horsetail
Helianthus annuus	Common sunflower
Juncus balticus	Baltic rush
Kochia scoparia	Belvedere summer cypress
Melilotus alba	White sweetclover
Populus angustifolia	Narrowleaf cottonwood
Sagittaria latifolia	Broadleaf arrowhead
Scirpus acutus	Hardstem bulrush
S. americanus	Common threesquare
Sitanion hystrix	Squirreltail
Sporobolus airoides	Sacaton
Typha latifolia	Broadleaf cattail

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[a] Names according to Hotchkiss (1967, 1970) and Plummer *et al.* (1977).